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(54) Title: FABRICATION OF CONDUCTIVE/NON-CONDUCTIVE NANOCOMPOSITES BY LASER EVAPORATION (57) Abstract A composite layer of a sorbent, chemoselective, non-electrically-conducting polymer and nano-particles of an electrically conducting material dispersed throughout the polymer is formed on a substrate by pulsed laser deposition, matrix assisted pulsed laser evaporation or matrix assisted pulsed laser evaporation direct writing.		

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FABRICATION OF CONDUCTIVE/NON-CONDUCTIVE NANOCOMPOSITES BY LASER EVAPORATION

Background of the Invention

1. Field of the Invention

The invention relates generally to the deposition of materials and more specifically to the creation by laser deposition of composite layers of non-electrically-conducting polymers and electrically conducting particles..

2. Description of the Related Art

A chemiresistor is a chemical sensor made of a material that has an electrical resistance that varies in response to the presence or absence of an analyte. Typically, a chemiresistor comprises a composite coating of a non-conducting material (such as a chemoselective polymer) and a conducting material (such as carbon or metallic nanoparticles). The conducting material is dispersed throughout the non-conducting material with a sufficient density so that in the absence of an analyte, the chemiresistor conducts electricity. When the chemiresistor is exposed to an analyte, the analyte is absorbed by the non-conducting material, causing the composite coating to swell and causing the conducting particles to move farther apart from each other, thereby creating a measurable increase in electrical resistance through the coating.

Previously, chemiresistors have been made using conventional coating deposition techniques, such as spin coating, drop casting, or spray coating. These are "wet" techniques, meaning that they are processes that involve wetting a substrate surface with a mixture of the composite coating material and a solvent that volatilizes only after the deposit has been formed. For reasons discussed below, each of these techniques has the disadvantage that after the solvent evaporates, the resulting coatings tend to be non-uniform, lacking in homogeneity and imprecisely located. All of these factors are critical for the optimum performance of the chemiresistor.

With spin coating and aerosol spray coating, relatively large surface areas can be coated. However, it is difficult to achieve precise or accurate control of coating thickness with high reproducibility because of the difficulty in duplicating variables such as the cleanliness of the substrate, the viscosity of the solution, temperature conditions, the spin rate of the substrate and the delivery rate of the solution. Moreover, spin coating and aerosol spray coating are not well

1 suited for coating discrete, micron-sized substrate areas because of the difficulty of using
2 masking with these techniques.

3 Drop casting, which involves delivering a material to a substrate through a syringe using
4 an X-Y controlled stage or X-Y controlled syringe, allows for the coating of the discrete,
5 micron-sized substrate areas through the precise placement of single droplets of the solution on
6 the substrate. However, this technique provides inadequate control over the physical parameters
7 of the deposit.

8 Once a drop lands on the substrate surface, the final resting place of the polymer-conductor
9 material depends on the wetting of the solvent to the surface, surface tension of the solution, how
10 clean the surface is, the viscosity of the solution, both at the start and at all stages as the solvent
11 evaporates, the evaporation rate of the solvent, and the temperature of both the solution droplet
12 and the substrate, the vapor pressure of the solvent, and the colligative properties of the dissolved
13 materials that lower the vapor pressure of the solvent. Because the placement of matrix material
14 is controlled by the movement and evaporation of solvent molecules on the substrate surface,
15 there is little control over the shape of the resulting polymer-conductor film. Most deposits made
16 using the drop casting technique are rounded in shape when viewed from directly above. This
17 results from the initial spherical shape of the droplet that is deposited on the surface. There are
18 many other shapes possible that depend heavily on the degree of surface contamination. Substrate
19 surface areas that are relatively clean and are significantly wettable by the solvent solution (low
20 contact angle) result in significant spreading of the solution, and hence, a spreading of the
21 polymer-conductor material. In contrast, substrate areas that are contaminated and are not
22 significantly wettable by the solvent solution (low contact angle) result in a more localized
23 concentration of the solution (as indicated by larger contact angle) and thicker films of polymer-
24 conductor material.

25 An additional disadvantage of the three "wet" techniques described above is that as the
26 solvent evaporates from a deposit, an increasingly concentrated solution of the composite
27 material is formed, which may result in some degree of phase separation of the conducting and
28 non-conducting material through aggregate formation. As a result, the conductive material would
29 not be uniformly distributed through the polymeric film when all the solvent evaporated. Areas
30 of the polymer coating may not have the required quantity or uniform distribution of conductive
31 material to allow electrical conductance. The resulting performance of a sensor fabricated in this
32 fashion would be significantly impaired. If, in order to compensate for this deficiency, an

1 increased loading of conductive material is used, the physico-chemical properties of the coating
2 could be altered. For example, if a carbonaceous material is used as the conductive material
3 increasing the carbon loading causes the solubility properties of the coating increasingly reflect
4 the non-polar adsorptive properties of the carbon (see, for example, "Integrated Chemiresistor
5 and Work Function Microsensor Array with Carbon Black/Polymer Composite Materials", K.
6 Domansky, V. S. Zapf, J. Grate, A. J. Ricco, W. G. Yelton, and J. Janata, Proc. Solid-State
7 Sensor and Actuator Workshop, Hilton Head Island, South Carolina, June 8-11, 1998, pp187-190,
8 incorporated herein by reference.) An increase in non-polar adsorptive properties is undesirable
9 if the polymer properties have been tailored towards sorbing polar analytes.

10 **Summary of the Invention**

11 Accordingly, it is an object of the present invention to provide a coating of a composite
12 material of a non-electrically-conductive polymer and electrically conducting particles wherein
13 the electrically conducting particles are dispersed homogeneously throughout the non-
14 electrically-conductive polymer.

15 It is a further object of the present invention to provide a method of making a composite
16 coating of a non-electrically-conductive polymer and electrically conducting particles wherein
17 the thickness, uniformity, homogeneity, location and surface coverage of the coating are precisely
18 controlled.

19 These and other objects of the invention are achieved by a method of forming a layer of
20 a composite material of a non-electrically-conductive polymer and electrically conducting
21 particles wherein the layer is formed by laser deposition. The creation of the layer can be done
22 either by pulsed laser deposition, matrix assisted pulsed laser evaporation (MAPLE) or a direct
23 write form of matrix assisted pulsed laser evaporation (MAPLE-DW).

24 **Brief Description of the Drawings**

25 A more complete appreciation of the invention will be readily obtained by reference to
26 the following Description of the preferred Embodiments and the accompanying drawings.

27 Figure 1 is a schematic representation of the method for creating a composite layer by pulsed
28 laser deposition.

29 Figure 2 is a schematic representation of a segmented target.

30 Figure 3 is a schematic representation of the method for creating a composite layer by pulsed
31 laser deposition, using a separate target for the polymer and the conducting particles.

32 Figure 4 is a schematic representation of the apparatus for creating a composite by matrix

1 assisted pulsed laser evaporation direct write.

2 Figures 5a and 5b are schematic representations of the laser transparent substrate, the coating and
3 the receiving substrate before (5a) and after (5b) the depositing the non-electrically conducting
4 polymers and electrically-conducting particles on the receiving substrate by matrix assisted
5 pulsed laser evaporation direct write..

6 Detailed Description of the Preferred Embodiments

7 The present invention relates to composite films or layers made up of non-electrically
8 conducting polymers, such as chemoselective polymers, and electrically-conducting particles,
9 the layers having physical properties of uniform thickness, homogeneity and precise placement
10 that can only be achieved through methods of laser deposition. The methods of laser deposition
11 that may be used in the present invention include pulsed laser deposition (PLD), matrix assisted
12 pulsed laser evaporation (MAPLE) or a direct write form of matrix assisted pulsed laser
13 evaporation (MAPLE-DW).

14 The non-electrically conducting polymer is preferably a sorbent chemoselective polymer,
15 that is, a polymer such as polyepichlorohydrin (PECH) that is chosen for its ability to interact
16 selectively with a particular chemical or biological analyte or which a particular class or type of
17 chemical or biological analytes. Criteria for selecting non-electrically-conducting materials for
18 chemical sensing devices are described in detail in McGill et al, "Choosing Polymer Coatings
19 for Chemical Sensors", CHEMTECH, Vol 24, No. 9, pp 27-37 (1994) and in U.S. Patent
20 Application No. 08/864,320, filed May 28, 1997 by McGill et al for "Method of Producing a
21 Film Coating by Matrix Assisted Laser Evaporation" the disclosures of which are incorporated
22 herein by reference. Other examples of chemoselective materials include SXFA
23 (poly(oxy{methyl[4-hydroxy-4,4-bis(trifluoromethyl)but-1-en-1-yl]silylene})) and P4V (poly(4-
24 vinylhexafluorocumyl alcohol), perfluoro-polyethers terminated with a variety of functional
25 groups such as $\text{CF}_3\text{CH}_2\text{OH}$, polyethylene imines, polysiloxanes, alkylamino pyridyl substituted
26 polysiloxanes, polytetrafluoroethylene, polysilanes, polyesters, polyvinylaldehydes,
27 polyisobutylene, polyvinylesters, polyalkenes, zeolites, aerogels, porous carbon, metals,
28 silicalites, clay materials, cellulose materials, polyanilines, polythiophenes, polypyrroles,
29 fullerenes, cyclodextrins, cyclophanes, calixeranes, crown ethers, and organic dyes. Examples
30 of biochemical selective materials include antibodies, antigens, DNA, RNA, proteins,
31 oligopeptides, polypeptides, oligosaccharides, polysaccharides, and lipids.

32 The electrically conducting particles are preferably made of carbonaceous material (such

1 as, for example, graphite particles or carbon nanotubes) or metallic material (such as, for
2 example, gold). Preferably, the particles are nano-particles, that is, typically, particles in the size
3 range of 10 nm to 1000 nm.

4 The non-electrically-conducting polymer and the electrically conducting particles are
5 combined to form a target for laser deposition, according to the particular deposition method
6 being used, as described below. Typically, the loading of the electrically conducting particles in
7 the non-electrically-conducting polymer is about 20 % (w/w).

8 **Pulsed Laser Deposition**

9 The technique of pulsed laser deposition or pulsed laser evaporation is described
10 generally in Pulsed Laser Deposition of Thin Films, Chrisey, D. B.; and Hubler, G. K., Eds., John
11 Wiley & Sons, New York, 1994, incorporated herein by reference. For the present invention, the
12 laser target is formed by co-dissolving the non-electrically-conducting polymer and the
13 electrically-conducting particles in a solvent, and then subsequently removing the solvent. The
14 target is placed inside a deposition chamber, and the receiving substrate is placed in front of the
15 target at a distance of between 2 - 10cm. (To create a deposit that is limited to a select area, a
16 mask may be placed in front of the receiving substrate). As shown in Figure 1, a typical apparatus
17 100 useful for carrying out the method of the present invention includes a vacuum chamber 10
18 and a laser 12 (preferably a pulsed laser, such as, for example, KrF excimer, 248nm; or ArF,
19 193nm) that is focused through lens 14 onto target 16, which is made of a mixture of the non-
20 electrically-conducting polymer and the electrically-conducting particles. The target 16 is affixed
21 to rotating arm 18 that allows plume 20 to be precessed over substrate 22, thus covering a wider
22 area than a fixed arm geometry would allow. Substrate holder 24 is electrically isolated and may
23 be heated by means of quartz lamp 26. The temperature is monitored by thermocouple 28. Gas
24 inlet port 30 allows the introduction of gases into chamber 10 in the direction of arrow 31.
25 Bubbler 32 (optional) may be used when a water vapor environment is desired. The chamber is
26 operated at a reduced pressure in the presence of an inert gas such as nitrogen or argon at 50
27 millitorr. The target material is exposed to the laser, which results in the transfer and co-
28 deposition of the and the electrically-conducting particles to the receiving substrate. A mask 34
29 may be interposed between the target and the receiving substrate so that a patterned deposit is
30 created.

31 In an alternative method of pulsed laser deposition, the target can be made up of discrete
32 segments, one segment containing the non-electrically-conducting polymer and the other segment

1 containing the electrically-conducting particles. TWhen the target is rotated, each segment is
2 alternately exposed to the laser, and alternating plumes of non-electrically-conducting polymer
3 and electrically-conducting particles are created and the non-electrically-conducting polymer and
4 the electrically conducting particles are alternately deposited on the substrate. If the target is
5 rotated quickly, a single-layer composite of the non-electrically-conducting polymer and the
6 electrically conducting particles is created. If the target is rotated slowly, a multilayer composite
7 having separate layers of the non-electrically-conducting polymer and the electrically conducting
8 particles is created. The segmented target is shown schematically in Figure 2, wherein a rotating
9 target, 310, includes a segment 312 having a non-conducting polymer and a segment 314 having
10 electrically conducting particles.

11 In another alternative, two targets, one with the non-electrically-conducting polymer and
12 one with the electrically conducting material, may be used in the same vacuum chamber and
13 irradiated, either simultaneously, to form a single-layer composite of the particles of the
14 electrically conducting material dispersed throughout the non-electrically-conducting polymer,
15 or alternatively, to form a multilayer composite having alternating layers of the particles of
16 electrically conducting material and the non-electrically conducting polymer. This embodiment
17 is shown in Figure 3, wherein lasers 125 and 126 are directed to strike target 74 having a non-
18 electrically-conducting polymer 76 and target 75 having electrically conducting particles 77 (or
19 a material that forms electrically conducting particles). By the action of the two lasers, the non-
20 electrically-conducting polymer and the electrically conducting particles are ablated from their
21 respective targets to form a composite on substrate 98.

22 23 **Matrix Assisted Pulsed Laser Evaporation**

24 The technique of matrix assisted pulsed laser evaporation is described generally in
25 following publications and patent applications, incorporated herein by reference: "Matrix assisted
26 pulsed laser evaporation (MAPLE) of functionalized polymers: Applications with chemical
27 sensors", Proc. SPIE Laser Applications in Microelectronic and Optoelectronic Manufacturing
28 III, R. Andrew McGill, , Douglas B. Chrisey, Alberto Pique, Todd E. Mlsna, San Jose, CA, 1998,
29 pp. 255-266; "Performance Optimization of Surface Acoustic Wave Chemical Sensors", R.
30 Andrew McGill, Russell Chung, Douglas B. Chrisey, Paul C. Dorsey, Paul Matthews, Alberto
31 Pique, Todd E. Mlsna, and Jennifer L. Stepnowski, IEEE Trans. on UFFC, 1998, 45(5), 1370-
32 1380, U.S. Patent Application No. 08/864,320, filed May 28, 1997 by McGill et al for "Method

1 of Producing a Film Coating by Matrix Assisted Laser Evaporation"; and "Use of Matrix
2 Assisted Pulsed Laser Evaporation (MAPLE) For The Growth of Organic Thin Films", A. Pique,
3 D.B. Chrisey, B.J. Spargo, M.A. Bucaro, R. W. Vachet, J.H. Callahan, R. A. McGill, D.
4 Leonhardt, and T. E. Mlsna, Proc Mat. Res. Soc. Proc. Vol. 526, 1998, 421-426. The apparatus
5 for carrying the present invention may be the same as that used for pulsed laser deposition,
6 except that in this embodiment, the target is a matrix of the non-electrically-conducting polymer
7 and the electrically conducting particles co-dissolved or suspended in a binder, which may be
8 frozen. The freezing process can be simply achieved by immersion in liquid nitrogen or cooling
9 the container that contains the matrix solution. Additionally, for the polymer-solvent matrices,
10 the solvent can be prepared as a viscous solution or solvent swollen polymer target. In these
11 latter matrices, the target does not require freezing, even if the solvent is a liquid under the
12 operated chamber conditions. The target is placed inside a chamber, together with a substrate
13 to be coated placed in front of the targets at a distance of between 1 - 10cm, with or without a
14 mask placed in front of the substrate to be coated. The mask can be contacting or non contacting
15 the substrate to be coated. If a non contacting mask is used, a substrate-mask separation distance
16 of about 1 micron is optimum. The chamber is operated at a reduced pressure in the presence
17 of an "inert" gas such as nitrogen or argon at @ 50 millitorr. The target material is exposed to
18 a pulsed laser (e.g. KrF excimer, 248nm; or ArF, 193nm) which results in the transfer and co-
19 deposition of the polymer and conductive materials. The target is continuously rotated while the
20 deposition process is in progress. To further optimize the coating uniformity the substrate can
21 be heated either from a radiant heat lamp or by electrically heating the substrate to above the
22 melting point or glass transition temperature of the polymer.

23 EXAMPLE

24 For demonstration purposes, a glass substrate was prepared with 2 gold contact pads
25 separated by 1 mm gap. The gold pads were 500 x 500 μm in area, with a thickness of 1 μm .
26 The bare gap between the gold contact pads was masked so that deposition would occur to fill
27 the space between the electrodes. The frozen target of PECH/carbon/ CHCl_3 (composition 0.2g
28 carbon/gram of PECH) was exposed to a pulsed laser and the masked off area was coated with
29 the evaporated material. A visible PECH/carbon film was produced. The film thickness was
30 determined by profilometry at about 1 μm and a resistance of 100 K ohms was measured between
31 the 2 contact pads. On exposure to vapor, the resistance of the device increased. The resistance
32 recovered to its original signal level after removal of vapor. The PECH/Carbon films produced

1 by the above method were very uniform. Comparative photomicrographs (at X50 magnification)
2 of PECH/carbon coatings made by the method described above and PECH/carbon coatings made
3 by solvent drop casting show that the method of the present invention produces uniform coatings
4 whereas the method of solvent drop casting does not produce uniform coatings.

5 As with pulsed laser deposition, it is possible to carry out the matrix-assisted pulsed laser
6 evaporation with two separate targets, one with a mixture of the non-electrically-conducting
7 polymer and a solvent, and one with a mixture of the electrically conductive particles and a
8 solvent. Also, as discussed with respect to pulsed laser deposition, it is possible to carry out
9 matrix-assisted pulsed laser evaporation with a segmented, rotating target.

10 **Matrix Assisted Pulsed Laser Evaporation- Direct Write**

11 The technique of matrix assisted pulsed laser evaporation- direct write is described
12 generally the following patent application and publication, both incorporated herein by
13 reference: U.S. Patent Application Serial No. 09/318,134, filed by the present inventors on
14 May 25, 1999 for "MATRIX-ASSISTED PULSED LASER EVAPORATION DIRECT
15 WRITE" and "Laser Direct Writing of Active and Passive Circuit Elements," A. Pique, D.B.
16 Chrisey, R. Y. Auyeung, S. Lakeou, R. Chung, R. A. McGill, P. K. Wu, and W. Warren, in
17 Proc. SPIE Laser Applications in Microelectronic and Optoelectronic Manufacturing IV, San
18 Jose, CA, 1999, pp. In Press.

19 For this embodiment of the present invention, the polymer and the carbon or metal
20 (e.g., carbon or gold nano-particles) are co-dissolved or a suspension is formed in a solvent
21 and this coated onto a laser transparent support (typically called the "ribbon"). The laser
22 transparent support is exposed to a focused pulsed laser(s) (e.g. KrF excimer, 248nm; or ArF,
23 193nm) at atmospheric pressure under ambient laboratory conditions. The laser is directed
24 through the laser transparent support and strikes the matrix coating causing the coating to
25 desorb. A substrate is positioned so that the desorbed material is transferred to the substrate.
26 By moving the substrate and/or the laser, the composite material is transferred to the substrate
27 and any surface structure can be written to the substrate with the aid of a computer assisted
28 design program. The gap between the ribbon and the substrate can be varied from between
29 about 1 μm (25 μm practical with current equipment) to 100 μm in order to control the size
30 of the transferred spot, and the flux of material that strikes the substrate surface. The method
31 is schematically represented in Figure 3, 4a and 4b. The apparatus for carrying out matrix-
32 assisted pulsed laser evaporation direct write includes a pulsed laser 120 that emits pulsed

1 laser energy as depicted by arrow 140. The pulsed laser is positioned so that laser pulses travel
2 through the back surface of the target substrate and through the laser transparent support 150
3 to strike the coating 160, which comprises a mixture of the non-electrically-conducting
4 polymer and electrically-conducting particles. The coating may also include a binder. The
5 receiving substrate 180 is positioned so that when the coating desorbs from the target
6 substrate, the non-electrically-conducting polymer and the electrically conducting particles
7 are co-deposited on the receiving substrate. The laser, the target substrate and the receiving
8 substrate are connected to laser positioning means 200, target substrate positioning means
9 220 and receiving substrate positioning means 240, respectively. Figures 4a and 4b
10 schematically illustrate the effects of exposing the coating 160 to the pulsed laser energy 140,
11 whereby the coating 160 desorbs from the surface of the target substrate so that a mixture of
12 the non-electrically-conducting polymer and the electrically conducting particles 260 is
13 deposited onto the receiving substrate 180.

14 EXAMPLE

15 For a polyepichlorohydrin and carbon matrix, a ribbon was prepared by spin coating a
16 film of PECH/graphite on a quartz wafer, at a PECH/graphite thickness of @1 μm from a
17 solution in chloroform. The ribbon was exposed to a pulsed laser that transferred the
18 PECH/graphite matrix to a variety of substrates including glass, ceramics (e.g., alumina),
19 plastics (e.g., polyimide), circuit board composites, silicon and metal surfaces. For
20 demonstration purposes, a 500 nm X 400 μm X 250 μm bridge was fabricated over and
21 between two gold electrodes. The gold electrodes had previously been deposited on a printed
22 circuit board. Several test structures were prepared at different resistances. In general, on
23 exposure to an uncalibrated acetone vapor source, the chemiresistors ohmic resistance
24 increased by between 5 and 10% of the initial value 100 K ohm, and in less than 1 second..
25 After removal of the acetone, the resistances returned to their original values in
26 approximately the same time frame.

27 Obviously, many modifications and variations of the present invention are possible in
28 light of the above teachings. It is therefore to be understood that, within the scope of the
29 appended claims, the invention may be practiced otherwise than as specifically described.
30

Claims

What is claimed is:

1. A structure comprising a substrate and a layer of composite material deposited on the substrate, wherein the composite material comprises a non-electrically-conductive polymer and particles of an electrically conducting material dispersed throughout the non-electrically-conductive polymer, and wherein the structure is formed by a process of depositing the non-electrically-conductive polymer and the particles of electrically conducting material on the substrate by a method selected from the methods of pulsed laser deposition, matrix-assisted pulsed laser evaporation and matrix-assisted pulsed laser evaporation direct write.
2. The structure of Claim 1 wherein the layer of composite material has a thickness of between 1 nm and 1 mm and wherein the variation of thickness of the layer is less than plus or minus 10%.
3. The structure of Claim 1 wherein the identity of the non-electrically-conductive polymer, the identity of the particles of an electrically conducting material, the density loading of the particles of electrically conducting material and the location and thickness of the layer of composite material are selected so that the structure is a chemiresistor.
4. The structure of Claim 1 wherein the non-electrically-conductive polymer is a sorbent chemoselective polymer.
5. The structure of Claim 1 wherein the non-electrically-conductive polymer is an addition polymer or a condensation polymer.
6. The structure of Claim 1 wherein the particles of electrically conducting material are in the form of graphite particles, carbon nanotubes or fullerenes.
7. The structure of Claim 1 wherein the particles of electrically conducting material are

metallic nano-particles.

8. The structure of Claim 1 wherein the particles of electrically conducting material are organically functionalized metallic nano-particles.

9. A method of creating a layer of composite material on a receiving substrate, the method comprising the steps of

- (a) providing a source of laser energy
- (b) providing a receiving substrate
- (c) providing a target, the target comprising a mixture of a non-electrically-conductive polymer and particles of an electrically conductive material dispersed throughout the non-electrically-conductive polymer,
- (d) exposing the target to the source of laser energy so that the laser energy strikes the target and causing a portion of the mixture of a non-electrically-conductive polymer and particles of an electrically conductive material to desorb and be lifted from the target and wherein the target and the receiving substrate are oriented with respect to each other such that the mixture of a non-electrically-conductive polymer and particles of an electrically conductive material are transferred onto the receiving substrate, thereby forming a layer of composite material.

10. The method of Claim 9 wherein a mask is interposed between the target and the receiving substrate so that the mixture of a non-electrically-conductive polymer and particles of an electrically conductive material are transferred to only a preselected portion of the receiving substrate.

11. A method of creating a composite material on a receiving substrate, the method comprising the steps of

- (a) providing a source of laser energy
- (b) providing a receiving substrate
- (c) providing a rotatable target, the target comprising a first target segment including a non-electrically-conductive polymer and a second target segment including particles of an electrically conductive material,

(d) rotating the target while exposing the target to the source of laser energy so that the laser energy alternately strikes the first target segment and the second target segment, alternately causing the non-electrically-conductive polymer and the particles of an electrically conductive material to desorb and be lifted from the target and wherein the target and the receiving substrate are oriented with respect to each other such that the non-electrically-conductive polymer and the particles of an electrically conductive material are transferred onto the receiving substrate, thereby forming a composite material.

12. The method of Claim 11 wherein the target is rotated at a speed sufficiently fast so that when the non-electrically-conductive polymer and the particles of an electrically conductive material are transferred onto the receiving substrate, they become intermingled into a single layer of composite material.

13. The method of Claim 11 wherein the target is rotated at a speed sufficiently slow so that when the non-electrically-conductive polymer and the particles of an electrically conductive material are transferred onto the receiving substrate, they become form alternating layers of the non-electrically-conductive polymer and the particles of an electrically conductive material.

14. A method of creating a composite material on a receiving substrate, the method comprising the steps of

- (a) providing a first source of laser energy and a second source of laser energy,
- (b) providing a receiving substrate
- (c) providing a first target and a second target, the first target comprising a non-electrically-conductive polymer and the second target comprising an electrically conductive material,
- (d) exposing the first target to the first source of laser energy so that the laser energy strikes the first target and causes a portion of the non-electrically-conductive polymer to desorb and be lifted from the target
- (e) exposing the second target to the second source of laser energy so that the laser energy strikes the second target and causes a portion of the electrically conductive material to separate from the second target in the form of particles,

wherein the first target, the second target and the receiving substrate are oriented with respect to each other so that the non-electrically-conductive polymer and particles of an electrically conductive material are transferred onto the receiving substrate thereby forming a composite material.

15. The method of Claim 14 wherein steps (d) and (e) are carried out simultaneously so that a layer of composite material is formed on the substrate wherein the particles of the electrically conductive material are dispersed throughout the non-electrically-conductive material.

16. The method of Claim 14 wherein steps (d) and (e) are carried out alternatively so that alternating layers of non-electrically-conductive material and particles of the electrically conductive material are formed on the substrate.

17. The method of Claim 14 wherein a mask is interposed between the target and the receiving substrate so that the mixture of a non-electrically-conductive polymer and particles of an electrically conductive material are transferred to only a preselected portion of the receiving substrate.

18. A method of creating a layer of composite material on a receiving substrate, the method comprising the steps of

(a) providing a source of laser energy

(b) providing a receiving substrate

(c) providing a target substrate, wherein the target substrate has a surface, the surface being provided with a coating, the coating comprising a non-electrically-conductive polymer, particles of an electrically conductive material and a matrix material, and

(d) exposing the target substrate to the source of laser energy so that the laser energy strikes the coating and causes the coating to desorb and be lifted from the surface of the target substrate, whereby the matrix material volatilizes, and wherein the target substrate and the receiving substrate are oriented with respect to each other such that the electrically conductive material and the non-electrically conductive material are transferred onto the receiving substrate to form a layer of composite material.

19. The method of Claim 18 wherein a mask is interposed between the target and the

receiving substrate so that the mixture of a non-electrically-conductive polymer and particles of an electrically conductive material are transferred to only a preselected portion of the receiving substrate.

20. The method of Claim 18 wherein the matrix material is selected from the group consisting of addition polymers, condensation polymers, water, aromatic compounds, alcohols, ketones, aldehydes, esters, alkanes, thiols, phenols, carboxylic acids, amines, and heterocyclic organic compounds.

21. A method of creating a composite material on a receiving substrate, the method comprising the steps of

- (a) providing a source of laser energy
- (b) providing a receiving substrate
- (c) providing a rotatable target, the target comprising a first target segment having a first coating, the first coating comprising a non-electrically-conductive polymer and a first matrix material and a second target segment having a second coating, the second coating comprising particles of an electrically conductive material and a second matrix material,
- (d) rotating the target while exposing the target to the source of laser energy so that the laser energy alternately strikes the first target segment and the second target segment, alternately causing the non-electrically-conductive polymer/first matrix material or the particles of an electrically conductive material/second matrix material to desorb and be lifted from the target and wherein the target and the receiving substrate are oriented with respect to each other such that the non-electrically-conductive polymer and the particles of an electrically conductive material are transferred onto the receiving substrate, thereby forming a composite material.

22. A method of creating a composite material on a receiving substrate, the method comprising the steps of

- (a) providing a first source of laser energy and a second source of laser energy,
- (b) providing a receiving substrate
- (c) providing a first target and a second target, the first target having a first coating comprising a non-electrically-conductive polymer and a first matrix material and the second

target having a second coating comprising particles of an electrically conductive material dispersed throughout a second matrix material,

(d) exposing the first target to the first source of laser energy so that the laser energy strikes the first target and causes the first coating to desorb and be lifted from the target,

(e) exposing the second target to the second source of laser energy so that the laser energy strikes the second target and causes the second coating to desorb and be lifted from the target,

wherein the first target, the second target and the receiving substrate are oriented with respect to each other so that the non-electrically-conductive polymer and particles of an electrically conductive material are transferred onto the receiving substrate thereby forming a composite material.

23. A method for creating a layer of composite material on a receiving substrate, the method comprising the steps of

(a) providing a source of laser energy,

(b) providing a receiving substrate

(c) providing a target substrate comprising a laser-transparent support having a back surface and a front surface, wherein the front surface has a coating that comprises a non-electrically-conductive polymer, particles of an electrically conductive material and a binder,

(d) positioning the source of laser energy in relation to the target substrate and exposing the target substrate to pulsed laser energy so that the pulsed laser energy is directed through the back surface of the target substrate and through the laser-transparent support to strike the coating at a defined location with sufficient energy to cause the coating to desorb from the location and be lifted from the surface of the target substrate, whereby the binder volatilizes,

(e) positioning the receiving substrate in a spaced relation to the target substrate so that the non-electrically-conductive polymer and particles of an electrically conductive material in the desorbed coating are transferred onto the receiving substrate to form a layer of composite material at defined location on the receiving substrate.

24. The method of Claim 23 wherein the binder material is selected from the group consisting of addition polymers, condensation polymers, water, aromatic compounds, alcohols, ketones,

aldehydes, esters, alkanes, thiols, phenols, carboxylic acids, amines, and heterocyclic organic compounds.

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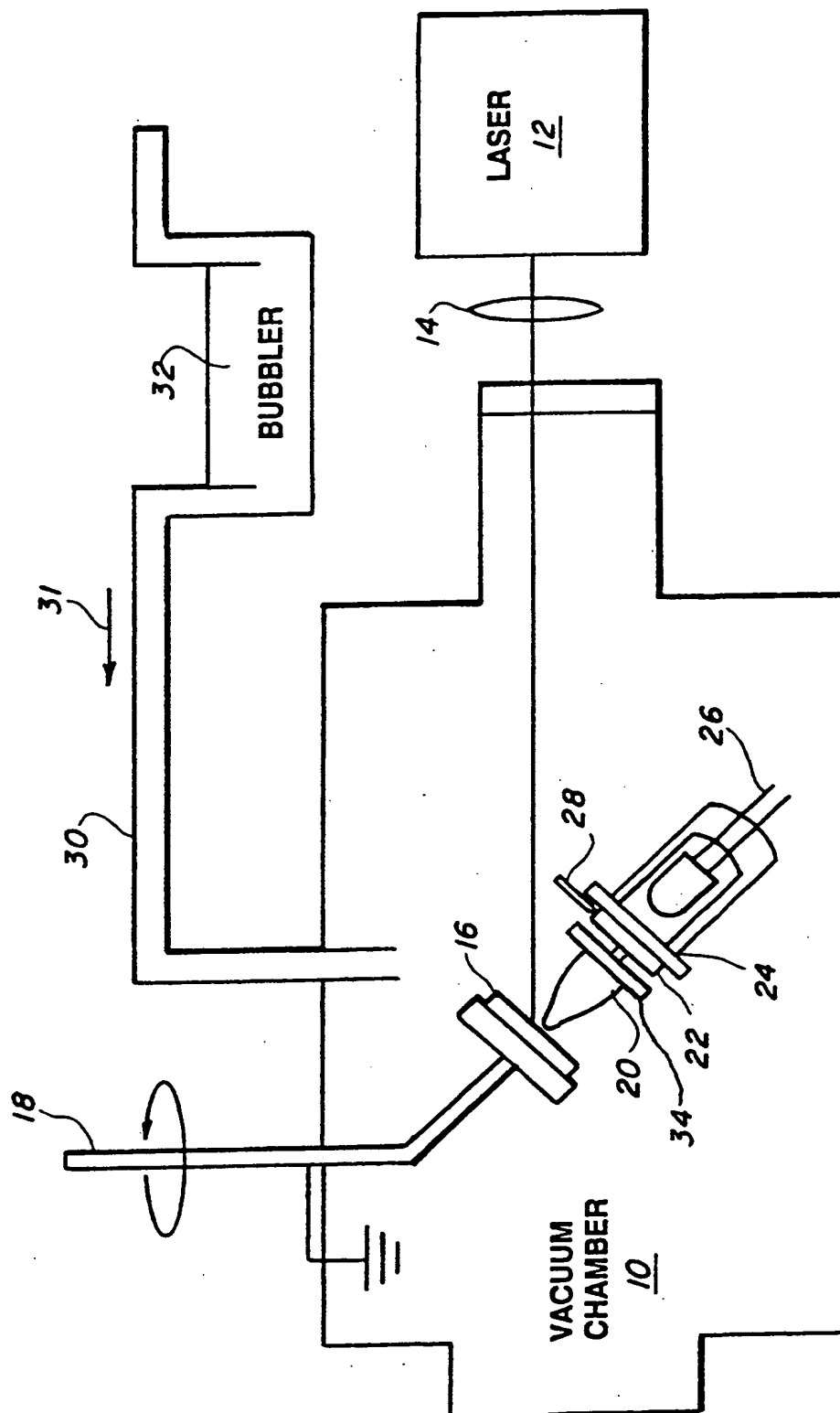


FIG. 1

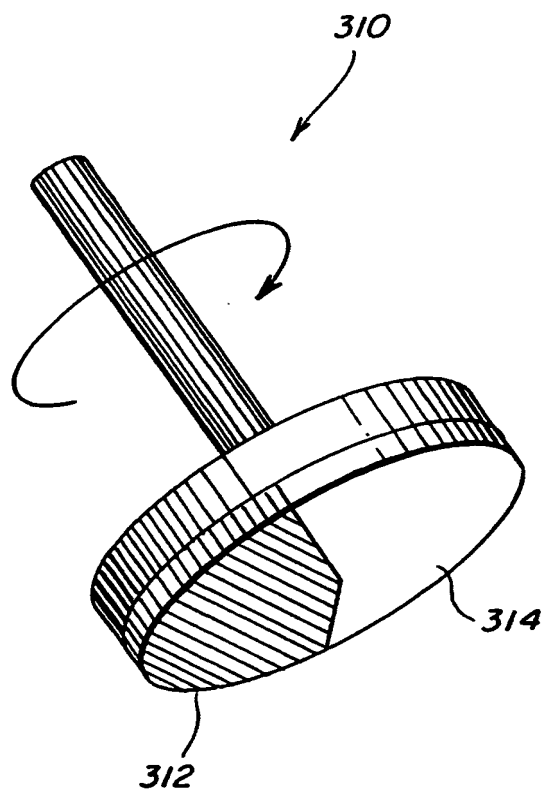
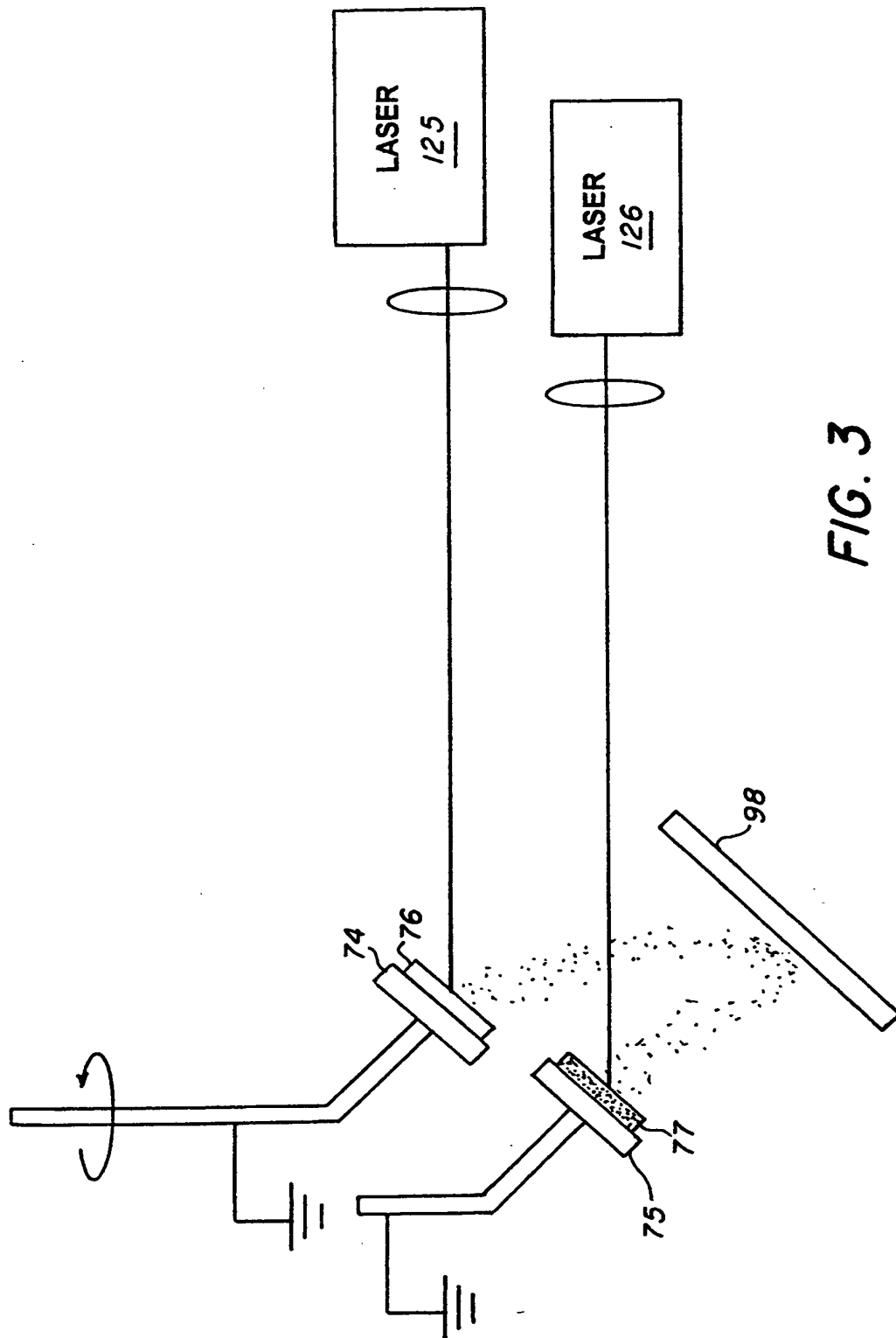
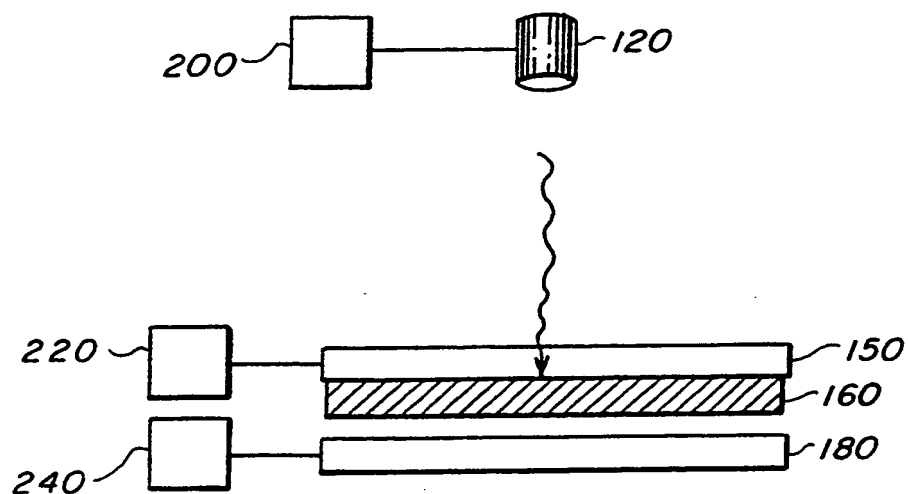
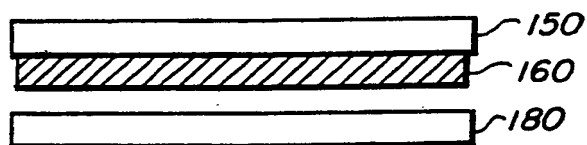
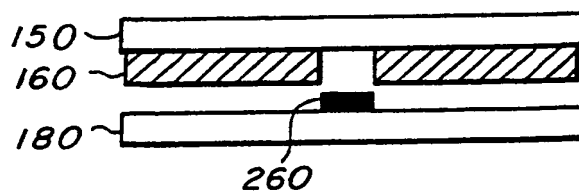


FIG. 2

**FIG. 3**

**FIG. 4****FIG. 5a****FIG. 5b**